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Options for Mitigating Greenhouse Gas Emissions in Guiyang, China : A Cost-Ancillary Benefit Analysis

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This report provides information on the additional "ancillary" benefits that China would experience by reducing emissions of the greenhouse gas carbon dioxide. It investigates a number of options for mitigating CO2 emissions in the power and industrial sectors of Guiyang City. It calculates the impact these options would have on the city's overall air pollution and effects these changes in air quality would have on the health improvements and looks at the overall cost and benefit that each of the carbon dioxide reduction technologies would bring to society as a whole.

It finds that a number of technologies would not only help address the problem of global warming but improve the quality of the city's air and the health of its people. Over time, these would pay themselves in terms of reduced mortality and illness levels.

The report recommends that the government should support and legislate for such "no regrets" carbon dioxide reduction initiatives. It also recommends that similar studies be done in other cities to identify options suitable for those cities' conditions.

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April, 2004

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EEPSEA was established in May 1993 to support research and training in environmental and resource economics. Its objective is to enhance local capacity to undertake the economic analysis of environmental problems and policies. It uses a networking approach, involving courses, meetings, technical support, access to literature and opportunities for comparative research. Member countries are Thailand, Malaysia, Indonesia, the Philippines, Vietnam, Cambodia, Lao PDR, China, Papua New Guinea and Sri Lanka.

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ABBREVIATIONS

AA…………………………………..Asthma Attacks
AFBC…………………………….....Atmospheric Fluidized Bed Combustion
ARS…………………………………Acute Respiratory Symptoms
CABA………………………………Cost-Ancillary Benefit Analysis
CB………………………………….. Chronic Bronchitis
CDM……………………………….. Clean Development Mechanism
CO_2…………………………………Carbon Dioxide
COI…………………………………Cost of Illness
EIA…………………………………Environmental Impact Assessment
EPB…………………………………Environmental Protection Bureau
ERV…………………………………Emergency Room Visits
FDI…………………………………Foreign Direct Investment
GASCC…………………………..... Gas Turbine Combined Cycle
GDP…………………………………Gross Domestic Product
GHG…………………………………Greenhouse Gas
IGCC……………………………….. Integrated Gasification Combined Cycle
IPCC…………………………………Intergovernmental Panel on Climate Change
IRR………………………………....Internal Rate of Return
KP…………………………………..... Kyoto Protocol
NO_x…………………………………Nitrogen Oxide
NPV…………………………………Net Present Value
OILCC………………………………Oil Fired Combined Cycle with unit capacity of 100MW and above
ODA…………………………………Official Development Assistance
PFBC………………………………..Pressurized Fluidized Bed Combustion
PM_{10}…………………………………Particular Matter (diameter <10 micro-meters)
$PM_{2.5}$…………………………………Particular Matter (diameter <2.5 micro-meters)
RAD…………………………………Restricted Activity Day
RHA…………………………………Respiratory Hospital Admissions
SDPC………………………………..State Development Planning Commission
SEPA………………………………..State Environmental Protection Agency
SO_2……………………………………...Sulfur Dioxide
SO_X……………………………………..Sulfur Oxide

SOE…………………………………State Owned Enterprise

TSP…………………………………Total Suspended Particulates

UNDP………………………………United Nations Development Programme

OPTIONS FOR MITIGATING GREENHOUSE GAS EMISSIONS IN GUIYANG, CHINA: A COST-ANCILLARY BENEFIT ANALYSIS

Jing Cao

EXECUTIVE SUMMARY

This paper argues that it is possible to simultaneously achieve reductions in both Greenhouse Gas (GHG) emissions as well as local air pollutants such as sulfur dioxide (SO_2) and particulate matters in China. The benefits of such reductions are the so-called "ancillary benefits" of GHG mitigation, which are often ignored in current policy-making frameworks. This paper estimates the ancillary benefits of various GHG mitigation technology options related to coal consumption, such as the advanced electricity generation technologies of Integrated Gasification Combined Cycle (IGCC), Atmospheric Fluidized Bed Combustion (AFBC), Pressurized Fluidized Bed Combustion (PFBC), Oil Fired Combined Cycle (OILCC) and Gas Turbine Combined Cycle (GASCC). This paper also estimates the benefits of other mitigation options such as coal pretreatment, the renovation of existing old boiler systems and the application of new, efficient boiler systems in the industrial sector of Guiyang, China. To assess these GHG mitigation technology options, this paper applies a bottom-up or damage function approach to estimate the associated ancillary benefits. It then applies a new methodology – Cost-Ancillary Benefit Analysis (CABA) – towards policy decision-making for local governments.

The calculations of various GHG mitigation technology options in Guiyang suggest that these measures will bring about substantial ancillary benefits in both the electricity and the industrial sectors. Using best-guess dose-response functions and unit values for estimating health impact endpoints, the ancillary health benefits are estimated at 89-278 USD/tC (US dollars per ton carbon). Using CABA to rank the selected GHG mitigation technology options, the results show that AFBC is preferable in terms of maximizing net present values compared with other electricity generation options in the electricity sector when the discount rate is less than 15%. In the industrial sector, however, whether governments adopt the coal pretreatment and boiler renovation option or apply new and efficient boiler systems would depend on the sensitivity of the discount rate. A crude CABA estimates that when the discount rate is less than 8%, the coal pretreatment and boiler renovation option is better, and when discount rate is greater than 8%, applying new and efficient boiler systems is preferable. The CABA results also prove that "no regrets" GHG mitigation options do exist for both electricity generation technologies and industrial boiler improvement. Therefore the latter part of this paper discusses China's current climate change-related energy policies and institutional frameworks. Also, barriers and opportunities for China's implementation of GHG mitigation options are analyzed and recommendations are proposed for future policy formulation and decision-making taking into account global climate changes and local environmental benefits in China.

1.0 INTRODUCTION

As the second largest emitter of greenhouse gas (GHG) and the most populous country in the world, China currently accounts for about 13% of global carbon dioxide emissions, mostly because of its high reliance on coal consumption and sharply increasing demand for automobiles (IEA 2000). This figure is expected to rise over future decades. With an average 7% Gross Domestic Product (GDP) growth rate, the energy system plays a critical role in economic development to sustain increasing energy demands with rapid economic growth. Although as a developing and non-Annex I country, China is not bound to any GHG emission or carbon abatement limits during the first control period (from 2008 to 2012) of the Kyoto Protocol (KP), China announced at the World Summit on Sustainable Development held in Johannesburg, South Africa on 3 September, 2002, that it has completed the domestic procedures for the approval of the Kyoto Protocol, and will play an active role in mitigating GHG emissions (Zhu 2002).

Clean Development Mechanism (CDM) projects create new investment opportunities for developing countries. The competition to attract early CDM funding to reap potential benefits from the technology transfer also encourages China to seek international cooperation on climate change research and take abatement action in the near future. In other words, the earlier China participates in the CDM projects, the earlier China benefits from these “win-win” projects.

China’s positive stance towards the Kyoto Protocol and sustainable development poses a challenge for current climate change studies in China. Recent China studies on climate change have mostly focused on the direct effects of global climate changes by using complicated global climate change modeling. For example, the PRC Climate Change Country Study Team (2000) modeled the impact of climate change on agriculture, forestry, water resources, and sea level changes as well as climate change-related diseases. However, these climate change studies have not persuaded current policy makers to implement GHG activities voluntarily to combat the global climate change problem. There are two key reasons for this situation. Firstly, cost-effective decision-making is still very weak in China, especially at local government level, and information on cost-benefit analyses is not effectively disseminated – the Chinese government especially at the local level typically is not aware of the associated environmental benefits and mitigation costs. Secondly, climate change studies are a young science. Since the benefits of climate change are public goods from an economic standpoint, no one country has an incentive to mitigate carbon emissions. For these reasons, the Chinese government does not have strong incentive to contribute towards reducing the rate of global warming.

The increasing amount of recent literature on ancillary benefits sheds some new light for practical policy decision-making, and builds a bridge linking global climate change benefits with local sustainable development. Many research studies conducted in both developed and developing countries have found that the mitigation of GHG usually leads to reductions in associated externalities, such as emissions of sulfur dioxide (SO_2), particulate matter, and other pollutants, some of which are hazardous to human health and the natural environment. The benefits from avoiding associated damage to human health and the natural environment by reducing conventional pollutants are called "ancillary benefits" or "collateral benefits" (Cifuentes et al. 1999; Burtraw and Toman 1997). More recent literature such as O’Connor et al. (2003); Aunan, Aaheim and Seip (2000); and Garbaccio, Ho and Jorgenson (2000) argue that GHG mitigation could be done with “no regrets” under certain conditions. In this paper, "no regrets" follows the Working Group II definition: a "no regrets" policy is one that requires immediate attention for it would generate net positive social benefits regardless of whether climate change happens or not (IPCC 2001a).

Since these ancillary benefits are rarely incorporated into cost-benefit analyses by the Chinese government, policy decision-making on climate change or other related policies, such as energy, environmental and agricultural policies, are prone to bias. This paper aims to shed some light on how to incorporate these ancillary benefits into the cost-benefit analysis framework for local governments by evaluating a variety of potential GHG mitigation technology options in Guiyang. The key research questions are: Should the local Guiyang government take GHG mitigation measures now or take a "wait-and-see" stance? What kind of GHG mitigation options in the technical field should be encouraged as priority by the government in their decision-making process? Are there "no regrets" in terms of social benefits? What problems will arise with the implementation of GHG mitigation, and how can these problems be solved?

This paper aims to answer these questions, by using a bottom-up approach – an approach focusing on individual processes from the micro-level perspective (Sathaye, Monahan and Sanstad 1996) – to estimate the ancillary benefits of various GHG mitigation technology options in local Guiyang. Then, a Cost-Ancillary Benefit Analysis (CABA)[1] for the selected GHG mitigation options is conducted. The results show that the ancillary benefits associated with the aforementioned GHG mitigation options are very significant in both the electricity sector and the industrial sector. Consequently, GHG mitigation can be done at low costs if ancillary benefits are considered. Under certain circumstances, GHG mitigation activities can even bring positive net benefits, or "no regrets". Finally, this paper investigates China's current energy policies and institutions, analyzes the barriers and opportunities associated with GHG mitigation activities, and proposes recommendations for promoting GHG mitigation activities in China.

The plan of this paper is as follows. In the following section, a brief literature review about recent ancillary benefits studies in both developed and developing countries is given. Section 3 focuses on methodology issues in estimating ancillary benefits and in the CABA framework. In Section 4, after a short background description of local Guiyang, several GHG mitigation options in the electrical and industrial sectors are identified. Section 5 presents the air dispersion model and related simulated results. Section 6 calculates the total ancillary benefits from averted mortality and morbidity endpoints, and a CABA is conducted for each technology option. Section 7 concludes and discusses existing barriers to and opportunities for implementing "no regrets" projects, and proposes some policy recommendations for China's future policy-making on accommodating both global climate change and local environmental benefits.

2.0 LITERATURE REVIEW

Some studies already exist concerning the ancillary benefits of GHG mitigation measures, but most look at state level climate policy options such as carbon tax or tradable permits, and ignore the ancillary benefits of specific technology options. For example, Garbaccio, Ho and Jorgenson (2000) estimated the local health benefits with an imposed

[1] Cost-Ancillary Benefit Analysis (CABA) is defined here specifically to include not only the financial costs and benefits, but also the indirect ancillary effects, except for climate benefits.

carbon tax to reduce 5% and 10% of CO_2 emissions by using an economic-wide computable general equilibrium (CGE) model. Through a two-region CGE model, O'Connor et al. (2003) estimated that a 10% reduction of CO_2 in 2010 would be optimal in terms of both welfare costs and ancillary benefits in agriculture and public health and could be achieved by imposing a carbon tax on the Chinese economy. However, the state level carbon tax is very sensitive to the choice of substitution coefficients and specific revenue recycling treatment. In addition, considering the difficulty of implementing a carbon tax at the national level, an alternative GHG mitigation policy would be to facilitate GHG mitigation technology options at the local level, since the ancillary benefits would be local, short-term benefits, and consistent with local environmental needs.

Gielen and Chen (2001) estimates the CO_2 emission-reduction benefits of Chinese energy policies and environmental policies for Shanghai for the time period 1995-2020 by using MARKAL modeling. This research also focuses on macro policy issues, and shows that the relevance of "no-regret" options (further improvements in efficiency) is limited because Shanghai has improved its energy efficiency significantly in recent years. Since Shanghai is the most developed city with the highest level of advanced technology in China, this research may underestimate the potential of GHG mitigation projects for other cities in China. Therefore this case is not representative of other cities, especially many median cities with a heavy industrial base and a lot of room for technological improvement. In the light of the "West & East Electricity Transfer" project in China, which involves setting up electrical power plants in western China and transporting the electricity to the eastern areas, whether the ancillary benefits are large enough is critical for decision-making on technology investments if local environmental pollution is taken into account. Therefore, this paper focuses on Guiyang, a representative big city involved in this project in southwestern China.

Besides macroeconomic modeling, there is other literature focusing on sector-level GHG mitigation options. Aunan et al. (2000) estimates the cost-benefits of CO_2 reduction measures for several sectors in Shanxi Province, and suggests that these measures could be profitable in a socio-economic sense. The researchers' methodology is simplified to estimate the population exposure, but does not identify the sources contributing to air pollution levels in a detailed geographical scale. This lack of detail is unfortunate, since the average ancillary benefit for a whole province may not truly represent the real benefits reaped in urban cities where the population density is high. The researchers also only focus on very crude carbon abatement options. Unlike the Aunan et al. (2000) report, this paper will use a detailed air dispersion model and focus on a more detailed geographical scale, an urban city scale, to help the local Guiyang government decide which GHG mitigation options are favorable.

There are also many studies focusing on the costs and benefits of reducing carbon emissions of each technology option but these technical reports ignore associated external environmental benefits. For this reason, this paper will try to combine detailed technology options and external environmental benefits to facilitate rational governmental decision-making.

3.0 METHODOLOGY

3.1 Damage Function Approach

The damage function approach, also called the impact pathway approach, is actually a bottom-up method for estimating impacts. The basic idea is to track the path of events beginning with the fuel-chain's activities, through the industrial life cycle process, to the emissions, the changes in the ambient concentrations („ambient concentrations' is a term to describe air pollution concentrations) of these pollutants, and then to incremental impacts resulting from these changes in concentrations. In this report, different pollution emissions for each technology option are first estimated, then the change in pollution concentrations is calculated by using the air dispersion model for Guiyang, and then the impacts assessed. Finally, the total external benefits – except for the long-term climate change benefits (i.e. ancillary benefits) – are calculated and valued in monetary terms. This report focuses only on the local benefits brought about by GHG mitigation options.

The impact pathway approach consists of three major steps of analysis (also see Figure 1) as follows:

a. Technology screening and characterization

The first step is technology option screening during which different GHG mitigation options are compared and the dominant options are eliminated based on cost and efficiency criteria. For instance, CO_2 depression technologies or cost-inefficient technologies are dropped from the option list because they are too expensive. Forestation projects are also eliminated for not being applicable to urban areas. In addition, local natural and environmental conditions are considered; for example, the local geographical and geological conditions of Guiyang are not appropriate for developing wind energy or subterranean heat energy; consequently these two technology options are also eliminated.

After the first round of elimination, the remaining technologies are often difficult to choose from, especially when a decision needs to be made on the trade-off between short-term cost efficiency or long-term environmental benefits and technical efficiency. Therefore, the screening process needs to examine the activities and engineering processes of each technology option in detail. For instance, with the electricity generation technology option, the following information has to be considered: type of power plant (e.g. coal-fired pulverized fuel); capacity of the power plant (in megawatts {MW}); efficiency and annual generation of the power plant (in megawatt-hours {MWh}); nature and annual amounts of discharge and other residual effects (e.g. SO_2, NO_X, particulate matter, etc.); pollution abatement equipment; and operational lifetime of the power plant (in years).

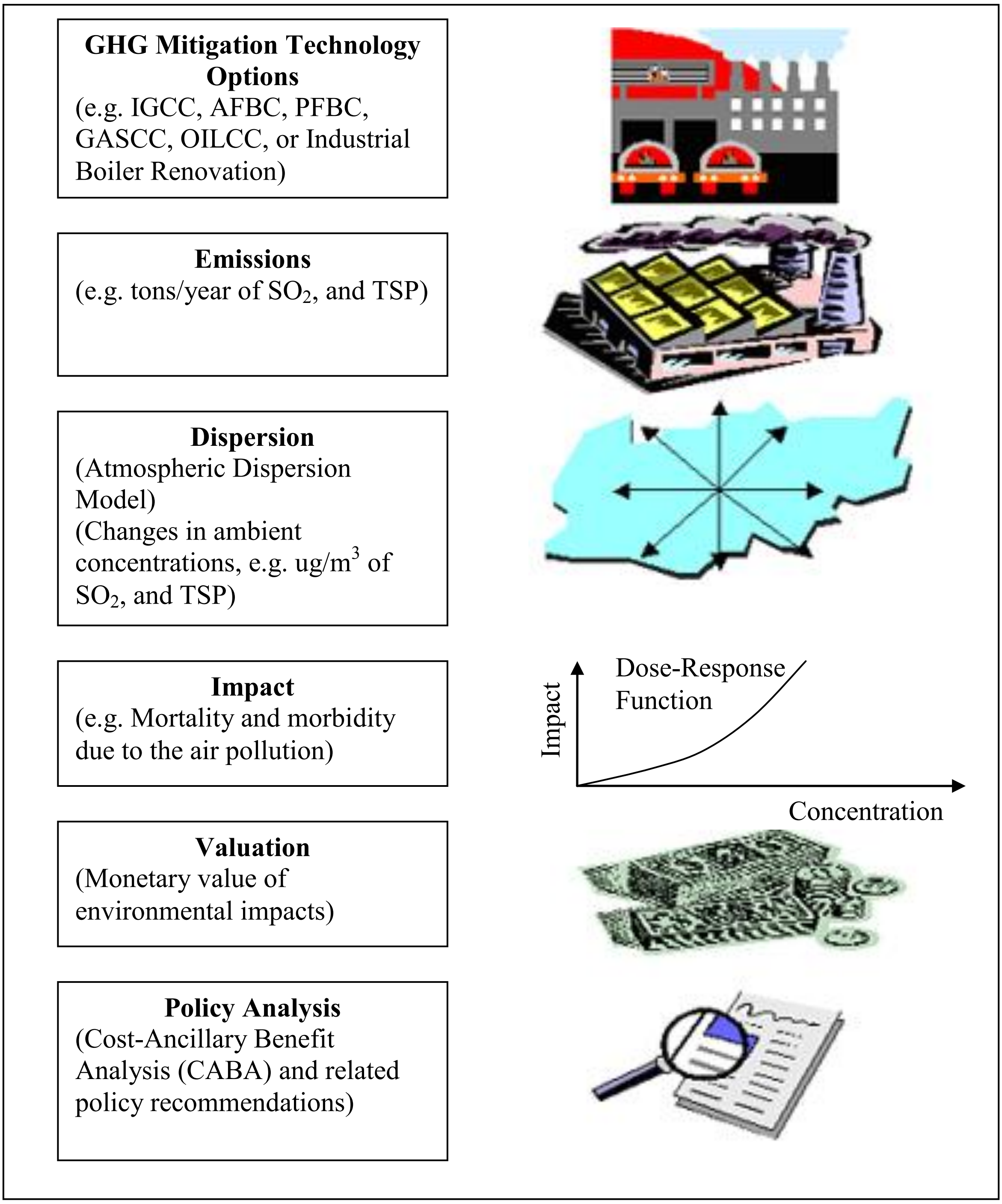

Figure 1. Flow chart of assessment of ancillary benefits by using the damage function approach

b. Calculation of changes in pollutant concentrations

The second step is to set up a local air dispersion model. In this study, an adjusted Gauss air dispersion model is used to simulate the change in concentration. The study area is divided into grids, and the pollutant concentration at the center of the grid is taken as the concentration of the grid area to predict the annual average ambient concentrations of pollutants for different scenarios, such as adopting advanced electricity generation technology or adopting industrial boiler renovation.

c. Calculation of expected impacts and cost-benefit analysis

Thirdly, the possible external environmental cost for each scenario is estimated. Two steps are followed: (i) an assessment of the physical impact of the different scenarios (by estimating population exposure and using dose-response functions), and (ii) a valuation of the benefits of the averted environmental health damages.

When the external ancillary benefits are estimated, the new “cost-ancillary benefit analysis” (CABA) method for quick decision-making is used to examine whether there are potential “no regrets” projects for the near future. CABA still follows the traditional methodology of a cost-benefit analysis (CBA) framework such as using net present value (NPV), but considers only the ancillary benefits while ignoring direct climate change benefits. If CABA shows that a project has a positive NPV in social-economic terms, it also holds that the NPV is positive when direct climate benefits are counted. (As long as the ancillary benefits exceed the total abatement costs, even if we add the unknown climate change benefits, the net present value of net benefits would still be positive. This has important policy implications.) This study’s CABA compares GHG mitigation technology options with baseline situations, that is, “do-nothing” or “business as usual” situations, where existing traditional technology is used.

3.2 Data Sources

The technical data and engineering characteristics were selected mainly from existing literature and technical reports. Such reports include Oskarsson et al. (1997), Asia Least-Cost Greenhouse Gas Abatement Strategy – People’s Republic of China (ADB 1998), the PRC Climate Change Country Study Team (2000) on climate change, the Harvard China Project power plant database, and technological GHG mitigation option evaluation projects conducted by the Energy Research Center, State Development Planning Commission (Hu and Jiang 2001).

In addition to the above data on GHG mitigation technology options, this paper also collected data on receptors and local geographical characteristics, on recent pollution monitoring, on meteorology (average wind velocity and direction, hourly wind velocity and direction, etc.) and on ambient baseline emission discharge for a baseline scenario. Most of the data was collected directly from the local Environmental Protection Bureau (EPB), the State Environmental Protection Agency (SEPA), and other government agencies. The pollution source data and specific energy consumption data of each key polluting enterprise were taken from a detailed city-wide industry pollution emissions and technology use survey conducted in Guiyang in 1996 and 1998.

4.0 GUIYANG: BACKGROUND AND MITIGATION OPTIONS

4.1 Features of Guiyang

Guiyang is located in the middle of Guizhou Province, on the eastern slopes of the Yungui Plateau. The urban area of Guiyang is a basin surrounded by high mountains; therefore it is very difficult for the pollution to disperse. Guiyang has a subtropical monsoon climate. It has mild seasons and plenty of precipitation. The prevailing wind direction during most of the year is north-east, but in summer the wind is south-easterly. The annual average wind velocity is 2.2m/s. The static breeze rate is 27%. All these meteorological characteristics cause the frequency and intensity of thermal inversion to be very high. (Thermal inversion is defined as the phenomenon where air pollution increases dramatically when cold air is trapped under warm air in the absence of air circulation.) At altitudes of 0m to 200m, thermal inversion occurs at a rate of 13.1%. This rate increases to 18.7% when the altitude is increased to 500m. In addition, this thermal inversion is fairly constant – about 80% of the days of the year. Therefore, the natural terrain of Guiyang and thermal inversion prevent pollutants from dispersing, causing severe pollution in Guiyang.

Guiyang is the capital of Guizhou Province and a key industrial base in southwest China. In 1996, Guiyang had a population of about two million, and ranked within the 150 most populated cities in the world (http://www.spokenamericanenglish.com/cities.htm). Guiyang's economy relies on its heavy industries, such as electricity, steel, chemicals, non-ferrous metals, and mechanotronics. The heavy industrial structure of Guiyang is the main reason for severe air pollution in Guiyang. In particular, coal is directly burned with a low transfer rate in many medium-small industrial boilers spread over the urban area. This has made the pollution more serious in recent years.

4.2 Air Pollution in Guiyang

In 1995, almost 96.4% of Guiyang's energy was generated from coal, with petroleum generating only 3.6%. In recent years, the percentage of coal-generated energy has decreased, but only slightly. Table 1 shows the coal levels consumed by the main industries in Guiyang City in 1995.

Table 1. Coal consumed by the main industries in Guiyang City in 1995

Industries	**Consumption (10,000 tons)**	**Converted equivalent coal (10,000 tons)**	**Heating power (million GJ)** (Giga Joules)	**Share in gross amount of total coal consumption (%)**
Electricity	419	299	88	50
Chemical	112	80	24	13
Non-ferrous metallurgical	75	54	16	9
Mechanotronics	30	21	6	4
Construction materials	37	27	8	4
Civilian	119	85	25	14
Others	54	37	11	6

Source: Integrated control program of sulfur dioxide pollution in acid rain control zones of Guiyang City, 25 December, 1998.

The main sources of air pollution in Guiyang are from electricity generation, steel plants, cement factories and medium-small industrial boilers spread widely throughout the urban area. Since Guiyang has begun to use natural gas as the main energy source in personal households, pollution from non-industrial sources is not so high and is therefore excluded from this study.

Guiyang is one of the most heavily polluted cities in China. In the 1990s, the average annual pollution concentration of sulfur dioxide (SO_2) exceeded the second level standard by three to nine times (Figure 2), and although there was a steady decline from 1995 to 1997, the concentration level was still three times above the second level standard. Although following a similar trend, the concentration of Total Suspended Particulates (TSP) was less serious than SO_2. It was, however, still high above the second level standard for every year except for 1997 (Figure 3).

Figure 2. Annual average concentrations of SO_2 in Guiyang

Source: GYAEMIS (2001).

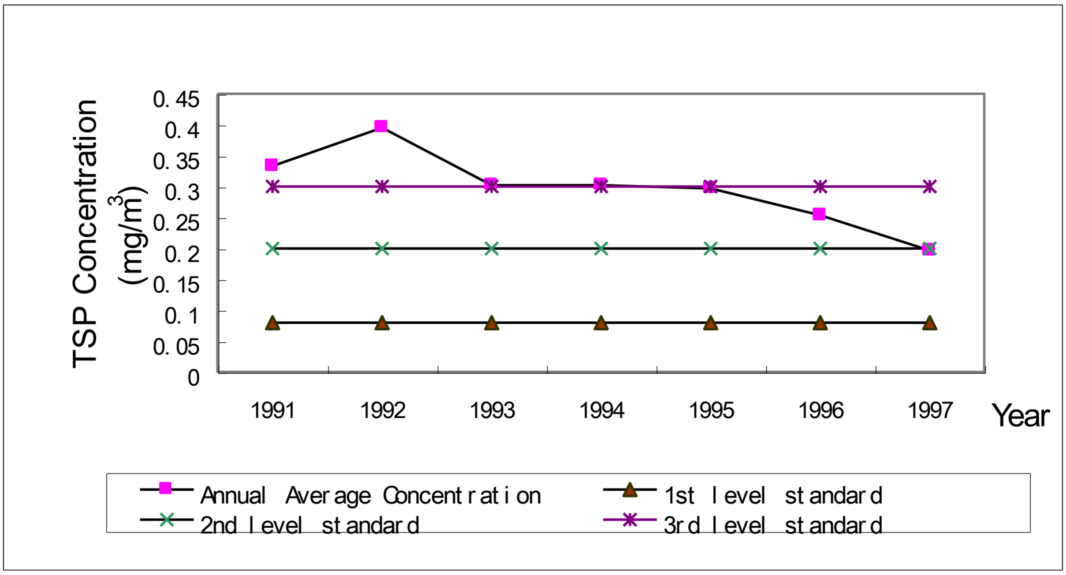

Figure 3. Annual average concentrations of TSP in Guiyang

Source: GYAEMIS (2001).

4.3 Available GHG Mitigation Options in Guiyang

As shown in Table 1, coal used in electricity generation accounts for about 50% of the total coal consumption. In addition, industrial boilers also consume plenty of coal for production and everyday heating. These two sectors are the biggest CO_2 emitters in Guiyang. There are abundant coal reserves in Guizhou Province, and most of the industrial production processes are highly reliant on coal. Therefore, coal-based technologies and their abatement strategies are more appropriate and cheaper than other advanced GHG mitigation options such as carbon sequestration.

4.3.1 Power Sector

According to ADB (1998) and Liu and Hao (in press) currently the most popular advanced GHG mitigation technologies are mainly in the power sector, namely, Integrated Gasification Combined Cycle (IGCC), Atmospheric Fluidized Bed Combustion (AFBC), Pressurized Fluidized Bed Combustion (PFBC), Oil Fired Combined Cycle (OILCC), and Gas Turbine Combined Cycle (GASCC).

Pulverized Coal (PC) Plant – Baseline Scenario

The pulverized coal (PC) plant technology is the oldest and most commonly used technology for thermal power generation worldwide. The market-based pulverized coal power plant design is actually based on the utilization of pulverized coal feeding a conventional steam boiler and steam turbine (Oskarsson et al.1997). Pulverized coal plants can be divided into two groups based on steam data: subcritical PC boilers and supercritical PC boilers[2]. The infrastructure investments of both types of PC boilers are the lowest, and allow huge amounts of SO_x (sulfur oxide) and NO_x (nitrogen oxide) to be emitted without end-pipe equipment. Generally, the net electricity efficiency of such boilers is about 32%, and their economic lifetime is about 30 years (Table 2). On investigating the Guiyang power plant and other power plants such as the Qingzhen power plant in Guizhou Province, it is interesting to note that almost all technologies and new planning projects still use subcritical boilers, which are less efficient than supercritical boilers. If this trend continues, pollution levels will remain severe in the years to come. Based on the concept of "business as usual", this technology could be viewed as a baseline scenario in Guiyang.

Integrated Gasification Combined Cycle (IGCC)

The IGCC technology is a very complex and effective electricity generation technology, and while some IGCC plants are in operation, most are still in the demonstration period. In a typical IGCC gasification process, electricity is produced in a gas turbine fueled by a synthetic gas, which is produced by the partial oxidation of coal in a gasifier. Steam, produced by synthetic gas cooling, drives a steam turbine. Sulfur is removed from the syngas before combustion (Oskarsson et al. 1997).

The net electricity generation efficiency is 39.5% (Table 2). Although IGCC is a very expensive technology option today, it has much potential to be further commercialized.

[2] Subcritical PC boilers and Supercritical PC boilers: "supercritical" boilers operate at a thermodynamic state (the state of a substance where there is no clear distinction between liquid and gaseous phases), usually at a higher pressure and temperature compared with "subcritical" boilers. Therefore, supercritical boilers usually have higher efficiencies evident in reduced coal consumption and reduced pollution emissions. (Oskarsson et al.1997, pp 20), and http://www.worldbank.org/html/fpd/em/supercritical/supercritical.htm#link4

Provided its investment cost can be reduced, it is likely to be the main combustion electricity technology option in the twenty-first century. In addition, with wide commercialization, electricity and initial investment costs will decrease greatly with the development and improvement maturity of the technology. Therefore it remains a very competitive option. Both PFBC and IGCC have been listed by China's electricity sector as priority projects since 2000.

Atmospheric Fluidized Bed Combustion (AFBC)

AFBC is a relatively new combustion technology in which carbon dioxide emissions are reduced substantially due to improved combustion efficiency, and sulfur is captured cost-effectively and directly in the furnace by limestone injection (Oskarsson et al. 1997). AFBC has a very high flexibility to fit specific local needs in developing countries, such as the building of new power plants, retrofit and boiler conversions, or combinations with coal-washing. In addition, AFBC is applicable to a wider range of fuels than conventional pulverized technologies, as such it can burn low-quality coal and coal cleaning waste; this property gives AFBC technology particular appeal in developing countries, especially China, where raw coal is widely used in electricity generation. This technology can achieve the removal of SO_2 up to 70 – 90% (World Bank 1995).

Pressurized Fluidized Bed Combustion (PFBC)

PFBC is an even newer technology than AFBC. It is a system which includes a combustor, a steam turbine, a gas turbine and other components. In a PFBC plant, power is generated in an integrated combined cycle with the hot gas from the combustor driving the gas turbine. Steam generated in the combustor powers a steam turbine. The main advantages of the PFBC are its low emissions and high efficiency (Oskarsson et al. 1997). The net electricity efficiency of a PFBC boiler is similar to IGCC's, about 39.5% (Table 2). In addition, PFBC works for old power plant renovations as well as for the setting-up of new plants. Therefore, it has a very wide market in China.

Gas Turbine Combined Cycle (GASCC)

The GASCC technology consists of one or more gas turbine generators equipped with heat recovery steam generators, by which energy in the gas turbine exhaust can be used for steam production. The common capacity of GASCC ranges from 50MW to 500MW (World Bank 1995). With superior improvements in firing temperatures and compression processes, the average efficiency of GASCC is about 40% (Table 2). In developed countries, this figure can rise to 50% (Northwest Power Planning Council 2002). Because of its low initial cost, high reliability, low levels of air pollutants and carbon dioxide emissions, GASCC has become an important technology option for electricity generation. However, its disadvantage lies in its expensive fuel costs.

Oil Fired Combined Cycle (OILCC)

Similar to GASCC, OILCC has the advantage of high efficiency, low initial costs and low pollutant emissions. Unlike GASCC which uses gas turbines, however, OILCC is fueled by crude oil and its initial capital investment is cheaper (Liu and Hao, in press).

Table 2 shows the key financial, technical and environmental characterisitics of the potential GHG mitigation technology options discussed above for Guiyang in the near future. Since China is just launching a new cross-provincial "West & East Electricity Transfer" project, the first three advanced electricity options; IGCC, PFBC, and AFBC, could become key GHG mitigation projects in this region. Technically, all five are all high-efficiency clean coal technologies with lower GHG emissions than traditional pulverized technologies; OILCC and GASCC combust oil or natural gas, so they emit less carbon dioxide than traditional coal technologies. Table 2 also shows that these five GHG mitigation technology options can not only reduce the emissions of carbon dioxide extensively, but can also reduce other emissions such as SO_2 and TSP, thus improving the local environmental quality of Guiyang. The key characteristics of each power plant technology are described as follows:

Table 2. Characteristics of advanced electricity generation technology options

Power generation technology options	**Capital investment** (USD/KW)	**Economic life** (year)	**Efficiency**	**Fuel cost** (cent/kwh)	**Fixed and variable costs** (cent/kwh)	**SO_2 emissions** (g/kwh)	**PM_{10} emissions** (g/kwh)
Baseline Subcritical Pulverized Plant	680	30	32%	0.968	0.871	10.97	0.957
IGCC	1150	30	39.5%	0.784	0.981	0.09	0.194
AFBC	950	30	37.5%	0.826	0.888	0.47	0.817
PFBC	1125	30	39.5%	0.784	0.969	0.44	0.582
OILCC	600	20	40%	2.331	0.58	0.62	0.361
GASCC	800	20	40%	2.079	0.8	0.04	0.032

Source: The data are from Liu and Hao (in press) representing the statistical averages from different sources (original sources: SETC, 2001; BMI, 1998; Murrary and Rogers, 1998; Hao & Lu, 1998; UNEP & NEPA, 1996).

4.3.2 Industrial Boiler Renovation

In addition to mitigation options in electricity generation, traditional energy-saving projects in industrial sectors can also have great impact on both carbon and air pollution reduction, such as coal pretreatment, renovating existing boiler systems or upgrading to more advanced and efficient boiler systems. Since most of the industrial boilers are concentrated in the urban area of Guiyang and most pollutants are emitted through low height stacks (emissions from low stacks have higher environmental impacts than emissions from higher stacks), the impact and damage from industrial emissions are larger in urban areas than those from electricity power plants located in the southwestern suburbs, although the latter accounts for the biggest coal use in Guiyang. For this reason, using industrial boiler renovation to mitigate GHG emissions is also very important in improving the local environment.

Coal Pretreatment and Renovating Existing Boiler Combustion Systems

Currently, most industrial boilers in Guiyang are using raw coal with high sulfur content, causing severe SO_2 and TSP pollution in the urban areas. Therefore, the first step in renovating industrial boilers would be coal pretreatment. Based on the type of boilers and conditions of use, several pretreatments could be used, such as coal selection, raw coal washing, or coal mixing or molding before stoking. The pretreatment would not only economize coal usage, but also reduce a lot of the sulfur content, making the combustion more efficient, and reducing carbon emissions as well. In addition, pretreatment would also reduce transportation costs, and prolong the life-span of the boilers, thereby further reducing costs substantially. In addition to coal pretreatment, reforming current boiler combustion systems by optimizing the combustion chamber or installing coal economizers and improving boiler management and workers' management skills will further increase efficiency. Based on the PRC Climate Change Country Study Team (2000), it is estimated that combustion efficiency could achieve a 10% improvement. All these measures described above have now been commercialized in China, and GHG mitigation at this level can be improved at a comparatively low cost.

New Efficient Boiler Application

Designing and producing high-efficiency industrial boilers by upgrading boiler structure is notably the most efficient way to improve boiler efficiency. Current commercial boilers include circulated fluidized-bed boilers, coal-casting machine combustion boilers and oscillating fire gate boilers. According to the research of the PRC Climate Change Country Study Team (2000), the average energy boiler efficiency could be improved by 20%[3] by applying advanced boiler technologies. Therefore, combustion efficiency would also be greatly improved, and the corresponding pollution emissions could also be reduced by about 20%.

4.4 Scenario Selection and Research Scope Definition

4.4.1 Scenario Selection

Based on the analyses of potential GHG mitigation technology options, two scenarios are defined below for comparison for each GHG mitigation technology option.

Baseline Scenario

The baseline scenario is actually a "business as usual" scenario, that is, no GHG measures will be taken in the near future. The current technology situation, energy consumption and pollution data set of 1998 will be used in this scenario.

Climate Change Mitigation Option Scenario

With respect to the baseline, each GHG mitigation technology option is examined for its relative ancillary benefits and costs. For example, in the electricity sector, IGCC, AFBC, PFBC, OILCC, or GASCC will replace the existing conventional pulverized coal-fired power plant, or mitigate GHG emissions with new efficient boiler systems.

4.4.2 Research Scope Definition

The research scope in this case study is defined as follows:

Geographical Region

This study only concentrates on the urban areas of the two districts of Yun-Ye and Nan-Min in Guiyang, where severe air pollution exists with high population density.

[3] The average efficiency improvement is estimated by the author by averaging over eight potential advanced boiler technologies.

Environmental Impact Factor and Receptors

Since NO_x pollution is very low and data on it was not available for this study, it is ignored in this report. Therefore, only SO_2 and TSP are considered in the ancillary benefit analysis. In addition, this ancillary benefit estimation does not consider ecological costs or benefits, but focuses only on the benefits to public health.

5.0 AIR DISPERSION MODEL AND SO_2 AND TSP CONCENTRATION DISTRIBUTION SIMULATION

An adjusted Gaussian plume Air Dispersion Model, formerly designed by Professor Li Jinlong at Peking University, was used in this study to predict annual average ambient concentrations of SO_2 and TSP for different scenarios.

The change in ambient concentrations is calculated by formula (1) below:

$$\Delta C_{Xi} = F\left(Q_{1X}\right) - F(Q_{0X}) \tag{1}$$

i = 1, 2, 3, …3600 (receptor cell id) (id = identification number index)

where $F(\cdot)$ represents the air dispersion model function, i represents each special receptor cell, Q_{1X} is the emission of pollutant x for each alternative GHG mitigation technology option, and Q_{0X} is the emission of pollutant x for the baseline technology option (x= SO_2, TSP).

Some of the parameters in this model were adjusted according to local meteorological and topological characteristics. The model uses meteorological data such as wind velocity and direction, and the characteristics of the emission source such as stack height, elevation and diameter, flue gas temperature, speed, etc. Each grid in the study region is 0.5 km × 0.5 km. Figures 4 and 5 show the average annual concentrations of SO_2 and TSP respectively, for the baseline scenario in Guiyang. Other GHG mitigation option scenarios have also been simulated. Figures 6 and 7 show the average annual concentrations of SO_2 and TSP dispersion after the replacement of the existing pulverized power plant with advanced IGCC technology. Similarly, Figures 8 and 9 illustrate the air dispersion results after the application of new efficient boiler systems in Guiyang.

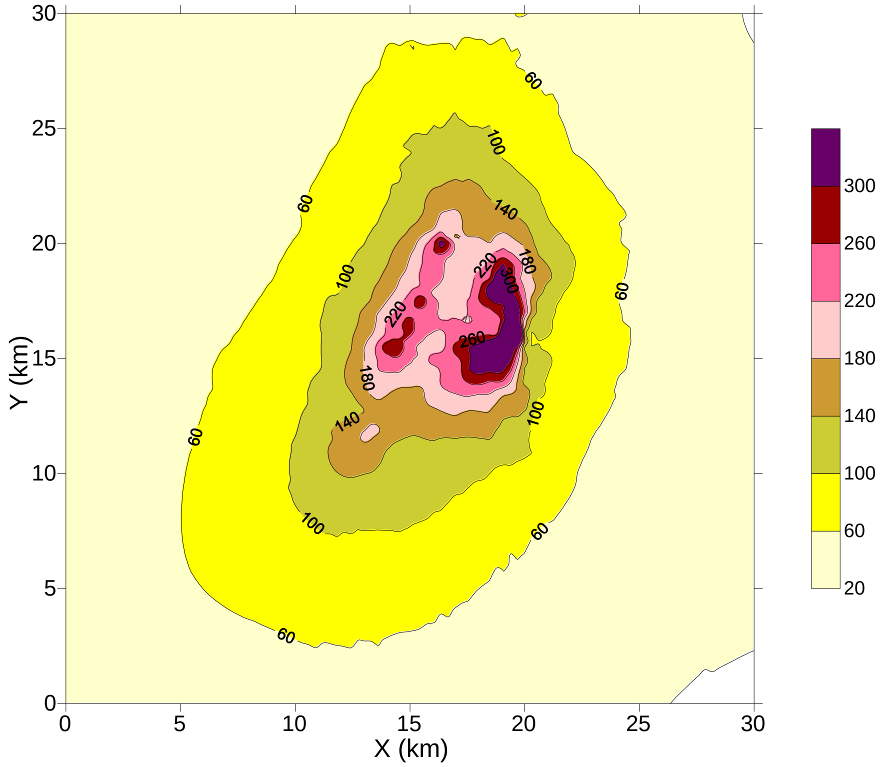

Figure 4. Isoline map of average annual concentration (ug/m^3) of SO_2 in the baseline scenario in Guiyang

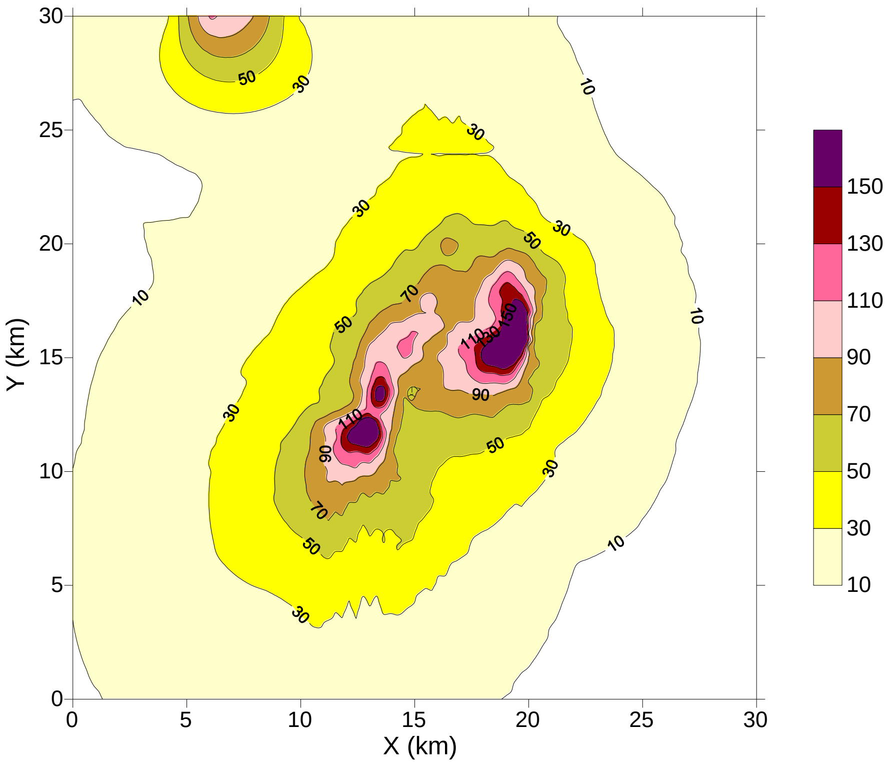

Figure 5. Isoline map of average annual concentration (ug/m^3) of TSP in the baseline scenario in Guiyang

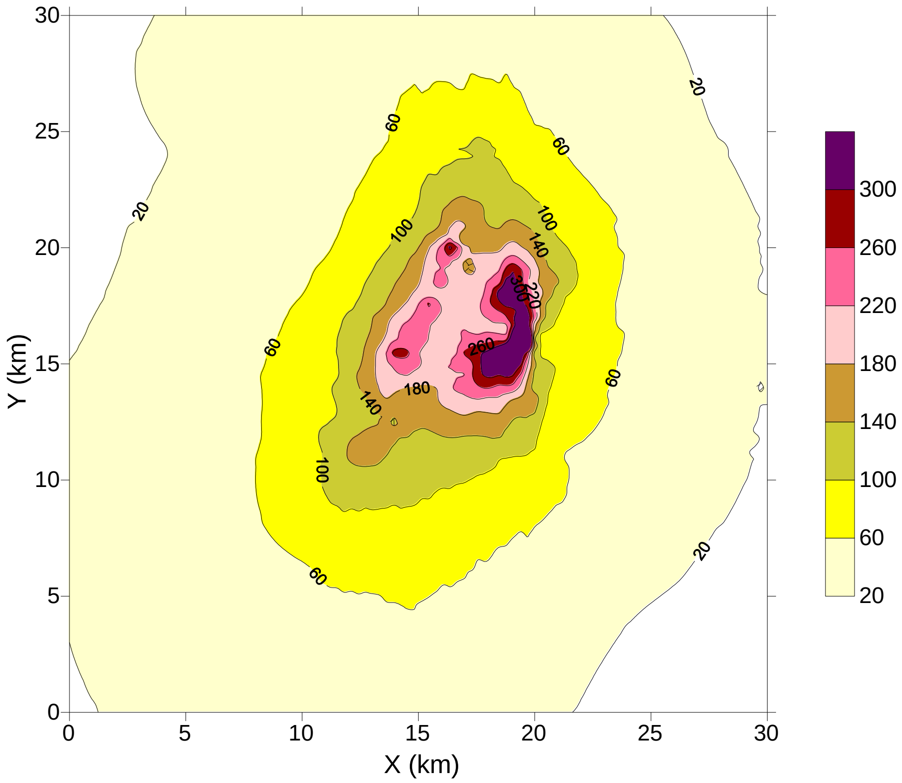

Figure 6. Isoline map of average annual concentration (ug/m^3) of SO_2 with IGCC in Guiyang

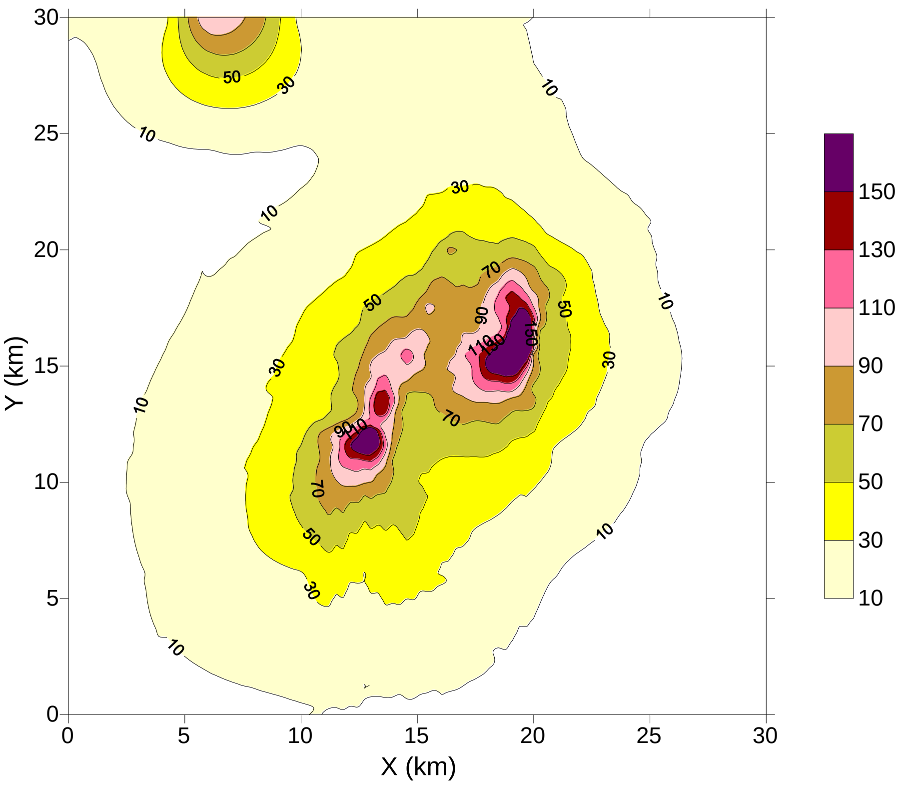

Figure 7. Isoline map of average annual concentration (ug/m^3) of TSP with IGCC in Guiyang

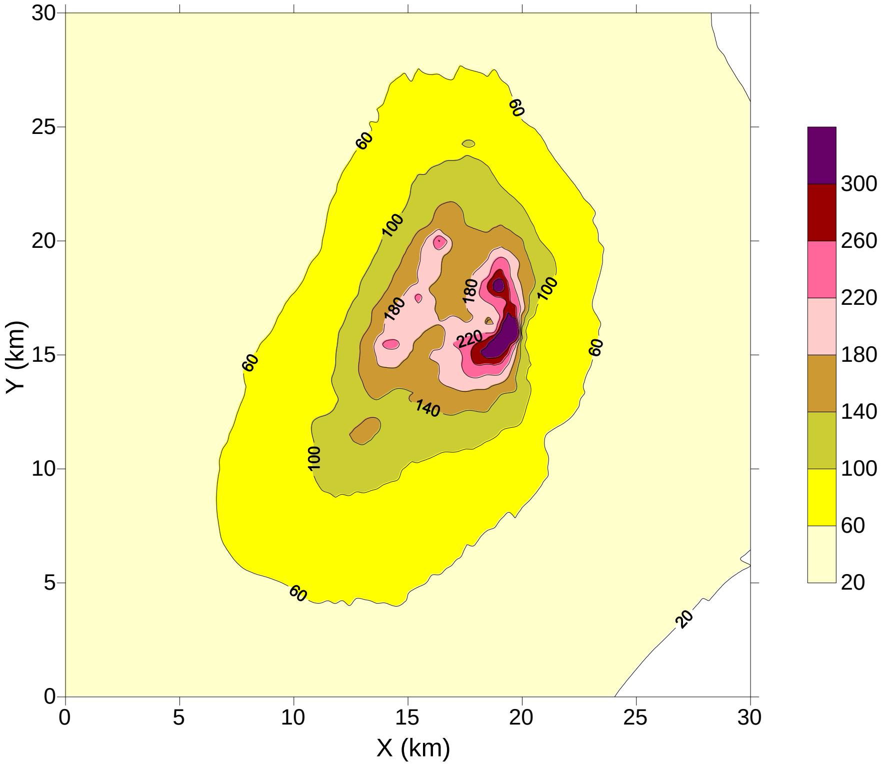

Figure 8. Isoline map of average annual concentration (ug/m^3) of SO_2 with new efficient boiler in Guiyang

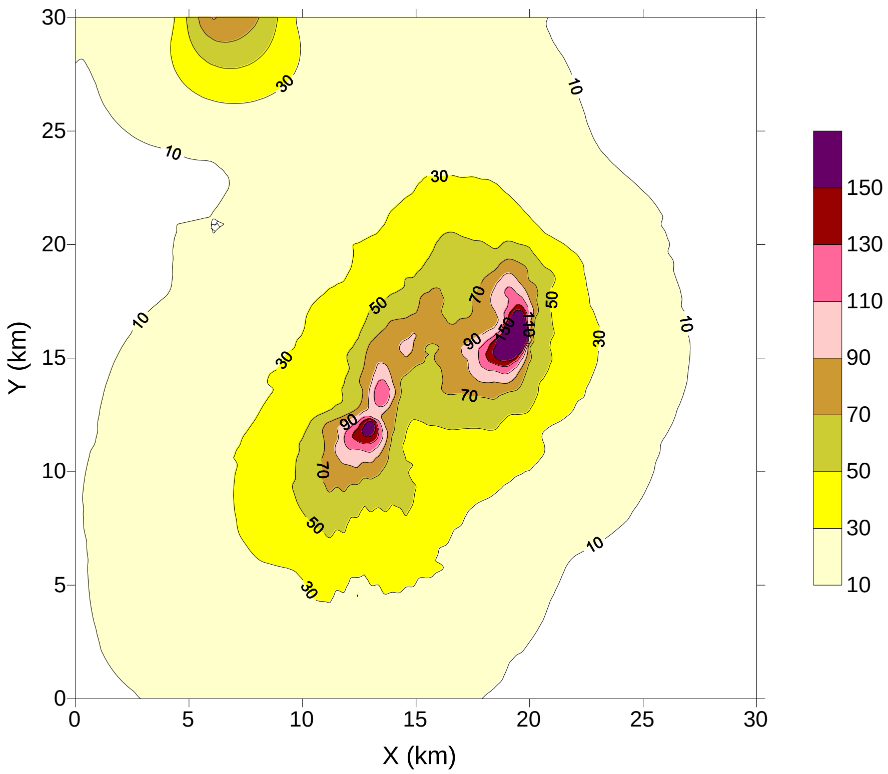

Figure 9. Isoline map of average annual concentration (ug/m^3) of TSP with new efficient boiler in Guiyang

6.0 ANCILLARY BENEFITS ASSESSMENT AND CABA ANALYSIS IN GUIYANG

Here, due to limitations on access to ecological data, ancillary benefits include only ancillary health benefits. In the calculation, the concentration of each grid is represented by its central point value. The population for each grid is then matched with its concentration, and dose-response functions and the population's risk of exposure are calculated to measure the ancillary health benefits.

6.1 Dose-Response Coefficients

The dose-response function indicates a reasonably consistent relationship between the incidence of mortality or morbidity, and ambient air pollution concentrations. Epidemiological studies in both developed and developing countries have derived consistent dose-response relationships. Therefore, calculated changes in pollution concentrations can be converted to equivalent changes in health effects.

For the particulate matter, although $PM_{2.5}$ (particular matter, diameter <2.5 micro-meters) or PM_{10} (particular matter, diameter <10 micro-meters) are the best measures for health effects, only TSP (total suspended particulate) was measured for Guiyang in the 1990s. PM_{10} is a specific form of TSP. In most western countries, PM_{10} is used for environmental inspection, but in China, TSP is used for environmental inspections and standards. In this paper, to apply the PM_{10} dose-response coefficients for Guiyang, it is assumed that PM_{10} is 55% of TSP (Rowe, Lang and Chestnut 1995; Dockery et al. 1996).

Table 3 lists the dose-response coefficient estimates for the various health endpoints, which include mortality, outpatient visits (OPV), emergency room visits (ERV), respiratory hospital admission (RHA), work day loss (WDL), asthma attacks (AA), acute respiratory symptoms (ARS) in children and adults, and chronic respiratory symptoms (CRS) in children and adults (based on existing epidemiological literature which distinguishes between adults and children for some health endpoints only). The dose-response coefficients in Table 3 are obtained from O'Connor et al. (2003), who conducted a human health impacts study in Guangdong Province. Their dose-response functions are based on Xu's (1998) indigenous epidemiological study of air pollution and health in urban areas of China.

Table 3. Dose-response coefficients of health effects: Change in annual number of cases per million people (all ages) per ug/m^3 change in PM_{10} and SO_2 concentrations

Health endpoints	Pollutant	Period per case	Dose-response coefficient (uncertainty interval)
Deaths	PM_{10}		2.2 (0−4.1)
	SO_2		12 (9−15)
Infant Deaths	PM_{10}		0.7 (0.4−0.9)
	SO_2		0.2 (0−0.6)
Outpatient Visits (OPV)	PM_{10}		4,670 (1,980−7,360)
	SO_2		1,800 (1,510−2,100)
Emergency Room Visits (ERV)	PM_{10}		55 (15−95)
	SO_2		186 (112−260)
Respiratory Hospital Admission	PM_{10}	14 days	56 (28−84)
(RHA)	SO_2	14 days	56 (28−84)
Work Day Loss (WDL)	PM_{10}		18,400 (9,200−27,600)
Acute Respiratory Symptoms in	PM_{10}	1 day	21,500 (14,190−32,470)
Children (<=14 years)	SO_2	1 day	2,830 (2,690−2,970)
Acute Respiratory Symptoms in	PM_{10}	1 day	28,320 (21,130−35,520)
Adults (> 14 years)	SO_2	1 day	7,650 (7,270−8,030)
Chronic Respiratory Symptoms in Children (<=14 years)	PM_{10}	About 1 year	15 (13−18)
Chronic Respiratory Symptoms in Adults (>14 years)	PM_{10}	About 1 year	34 (29−39)
Asthma Attacks (AA)	PM_{10}	1 day	1,770 (990−5,850)

Source: O'Connor et al. (2003). The dose-response coefficients are based on estimates for Guangzhou, China, cited in *Guangzhou Air Quality Action Plan – 2001*, February 2000, processed.
Note: Uncertainty interval represents ± 1 standard deviation.

6.2 Avoided Premature Mortality and Morbidity Effects

The ancillary health benefits from GHG mitigation can be derived from the benefits of avoiding premature mortality and morbidity. (Mortality effects refer to reducing the number of deaths due to the air pollution by reducing air pollution. Morbidity effects refer to mitigating the effects of illness or reducing cases of illness or hospital admissions.) Based on the dose-response functions above and local population distribution data[4], the changes in physical health effects are estimated by the following formula for each receptor cell,

$$\Delta HE_{Xh} = \sum_i (DR_{Xh}(\Delta C_{Xh}) POP_i) \tag{2}$$

h = Mortality, RHA, RAD, AA …; i = 1, 2, 3…3600

where DR_{Xh} is the dose-response coefficient for each pollutant X and health impact category h, and POP_i represents the population for each cell.

Table 4 shows the calculated results of health benefits for each mitigation technology option with respect to the baseline scenario, assuming that only pollution concentrations have been changed while all other factors such as population and geographical distributions are kept constant within the baseline scenario.

[4] Local population distribution data was collected from the local Guiyang EPB.

Table 4. Health benefits for different GHG mitigation options with respect to baseline scenario (unit: in cases per year)

Health endpoints	IGCC	AFBC	PFBC	OILCC	GASCC	Coal pretreatment and boiler renovation	Using new efficient boiler system
Deaths	153 (111-195) [1]	148 (107-188)	148 (107-188)	146 (106-185)	154 (111-195)	303 (222-384)	850 (603-1,090)
Infant Deaths	4 (1-10)	4 (1-9)	4 (1-9)	4 (1-9)	4 (1-10)	7 (1-18)	28 (8-59)
Outpatient Visits (OPV)	33,193 (23,277-43,231)	32,033 (22,464-41,722)	32,125 (22,528-41,841)	31,576 (22,143-41,125)	33,345 (23,384-43,430)	61,249 (44,361-78,384)	217,584 (142,297-293,541)
Emergency Room Visits (ERV)	2,422 (1,416-3,428)	2,337 (1,366-3,308)	2,344 (1,370-3,318)	2,304 (1,347-3,261)	2,433 (1,422-3,444)	4,780 (2,813-6,747)	13,606 (7,817-19,395)
Respiratory Hospital Admission (RHA)	822 (411-1,233)	793 (397-1,190)	796 (398-1,194)	782 (391-1,173)	826 (413-1,239)	1,582 (791-2,373)	4,915 (2,458-7,373)
Work Day Loss (WDL)	43,377 (21,689-65,066)	41,862 (20,931-62,794)	41,982 (20,991-62,973)	41,264 (20,632-61,897)	43,577 (21,788-65,365)	66,666 (33,333-99,999)	382,051 (191,026-573,077)
Acute Respiratory Symptoms (children)	21,061 (16,388-27,862)	20,363 (15,851-26,928)	20,421 (15,896-27,005)	20,072 (15,624-26,543)	21,197 (16,500-28,031)	36,396 (29,015-47,048)	156,852 (117,109-215,335)
Acute Respiratory Symptoms (adults)	121,329 (105,031-137,646)	117,092 (101,362-132,838)	117,426 (101,652-133,218)	115,419 (99,914-130,940)	121,887 (105,513-138,278)	219,245 (192,568-245,949)	829,231 (697,571-961,048)
Chronic Respiratory Symptoms (children)	9 (8-10)	8 (7-10)	8 (7-10)	8 (7-10)	9 (8-11)	13 (12-16)	77 (67-92)
Chronic Respiratory Symptoms (adults)	60 (52-69)	58 (50-67)	58 (50-67)	57 (49-66)	61 (52-70)	93 (79-106)	532 (454-610)
Asthma Attacks (AA)	4,173 (2,334-13,791)	4,027 (2,252-13,310)	4,038 (2,259-13,348)	3,969 (2,220-13,119)	4,192 (2,345-13,855)	6,413 (3,587-21,195)	36,752 (20,556-121,467)

Note: 1 represents the uncertainty intervals of ± 1 s.d. (standard deviation) by using range estimate of dose-response functions.

6.3 Valuation of Ancillary Health Benefits

The valuation of ancillary health benefits is a critical component of a cost-ancillary benefit analysis which affects decision-making. The goal of this step is to put monetary values on the health effects estimated in the sections above.

- **Mortality**

There are several existing methods to estimate the monetary value of premature death. The first approach is the human capital approach, which is used extensively in China by calculating the discounted present value of net foregone earnings due to premature death. The critical issue here is that no value is assigned to people who are not economically active, such as infants and the retired elderly, although it is these people who are most vulnerable to air pollution-related mortality (O'Connor et al. 2003). ECON Center for Economic Analysis (2000) further argues that the human capital approach is conceptually misleading, since there is no logical relationship between the willingness to pay for risk reduction and remaining lifetime earnings.

The second approach, called the value of statistical life (VSL) approach, estimates the price of reducing the risk of excess death (death due to working in a polluted environment as opposed to a non-polluted one) in the labor market. This approach usually introduces an ethical dimension to the estimation: VSL does not measure the value of life, but the price of reducing air pollution-related mortality risk (ECON 2000). In practice, hedonic wage studies and contingent valuation methods are usually used to estimate VSL. However, as Freeman (1993) points out, this approach ignores the individual's preference and overlooks the role of non-market production as well as the problem of sensitivity to the discount rate.

Ideally, the valuation of ancillary benefits should be based on the willingness to pay (WTP) approach, which reflects an individual's preference on environmental quality. In view of the technical, financial and temporal requirements for generating local WTP estimates, a benefit transfer (BT) approach is used to calculate the value of averted premature deaths. The World Bank (1997) „transfers' (i.e. applies) the mid-range VSL of about USD 3 million from the United States to China by using average income per capita adjustment – this results in about USD 60,000 per statistical life in urban areas. Similarly, the ECON Center for Economic Analysis (2000) estimates the unit value of mortality associated with air pollution to be about USD 77,000.

Only recently have Chinese researchers begun to conduct local/indigenous WTP studies for urban areas. For example, Wang et al. (2001) reported an average WTP for saving a statistical life to be about USD 34,750 by using the contingent valuation method (CVM) in Chongqing which can be derived to about USD 30,000 for urban Guiyang. Wang also calculated the marginal effects of income on WTP to be USD 14,550 with an annual income increase of USD 145.80. Zhang (2002) also used the CVM to elicit the Beijing residents' WTP on premature death (mortality) in 1999, and derived a unit value range from USD 60,000 to USD 200,000, which if transferred to Guiyang, would be about USD 19,000 to USD 62,000 after GDP per capita and consumer price index (CPI) adjustment.

O'Connor et al. (2003) transferred the Hammitt and Zhou (2000) estimate of USD 68,973 to Guangzhou Province – applied to Guiyang, the estimate would be USD 30,848, similar to the transfer value from the Chongqing indigenous WTP study. Therefore, based on the above indigenous and transfer studies, this paper treats the Wang and the O'Connor et al. studies as the central reference for mortality endpoint values, and takes the lower bound of Zhang's Beijing study as the lower bound (USD 19,000) for Guiyang, and the higher bound of the Beijing study and World Bank's estimate as the higher bound (USD 62,000) for Guiyang. (Higher bound refers to the highest World Bank estimate, and lower bound refers to the lowest World Bank estimate.)

- **Morbidity**

Due to the very limited WTP literature on the endpoints of hospital admissions, emergency room visits, and acute child bronchitis, this paper relied on the adjusted cost of illness (COI) approach for the valuation of these endpoints. However, the indirect cost components such as discomfort and intangible costs are neglected here. For the remaining health endpoints, such as asthma attacks, respiratory symptoms, and chronic adult bronchitis, the WTP values were estimated from various literature references which used benefit transfer approaches. Table 5 summarizes the selected unit values for mortality and morbidity effects, and the specific sources and types of estimates.

Therefore, based on the existing unit value of mortality and morbidity health endpoints and calculated total number of averted mortality and morbidity cases, the monetary valuation of ancillary benefits can be calculated by the following formula:

$$\Delta DAMAGE_h = \sum_X V_h \Delta HE_{Xh} \tag{3}$$

where V_h is the unit value of mortality and morbidity effects (Table 5).

The value of ancillary benefits can then be calculated by the change in total damage (4):

$$AB = \sum_h \Delta DAMAGE_h \tag{4}$$

where AB is total ancillary benefits derived from substituting existing baseline technology with clean technology options. The range estimate valuation of $\Delta DAMAGE_h$ for each mortality and morbidity endpoint and total ancillary benefits AB is listed in Table 6. The average ancillary benefits per ton of carbon are shown at the bottom of the table. Ostro (1996) pointed out that the central dose-response coefficients are "best guess" values. Similarly, by combining the central estimate of averted health effects with central unit values (See Table 5. The calculation uses formula 3 above.), we can get the "best guess" values for real-life situations.

Table 5. Benefit transfer unit values for mortality and morbidity effects on Guiyang citizens (in 1998 USD)

Health effects	Primary Source	Type of estimate	BT from literature (USD/unit)
Mortality/Infant Mortality	Wang et al. (2001); Zhang (2002); O'Connor et al. (2003); World Bank (1997);	WTP	30,848 (19,000, 62,000)[a]
Outpatient Visits (OPV)	O'Connor et al. (2003)	COI	6.47[b]
Emergency Room Visits (ERV)	Krupnick and Cropper (1992)	Adjusted COI	10.8 (5.5, 16.3)
Respiratory Hospital Admission (RHA)	Viscusi, Magat and Huber (1991)	Adjusted COI	285.9 (143, 428.9)
Work Day Loss (WDL)	O'Connor et al. (2003)	COI	1.33 [b]
Acute Respiratory Symptoms (children/adults)	O'Connor et al. (2003)	COI	0.47 [b]
Chronic Respiratory Symptoms	O'Connor et al. (2003)	COI	3888.71 [b]
Asthma Attacks (AA)	Loehman et al. (1979)	WTP	0.688 (0.241, 1.123)

Notes:

1. (a): Lower bound and higher bound for unit value of premature mortality.
2. (b): No lower bound and higher bound estimates available.
3. WTP: Willingness to pay
4. COI: Cost of Illness
5. BT: Benefit-transfer
6. The base year is 1998.

Table 6. Estimate of ancillary health benefits of GHG mitigation options with respect to baseline scenario (per year in thousands of 1998 USD)

Health endpoints	IGCC	AFBC	PFBC	OILCC	GASCC	Coal pretreatment and boiler renovation	Using new efficient boiler system
Deaths	4,722 (2,062-12,052)	4,557 (1,990-11,631)	4,570 (1,995-11,665)	4,492 (1,961-11,465)	4,744 (2,071-12,108)	9,362 (4,120-23,808)	26,215 (11,210-67,550)
Infant Deaths	127(18-590)	123(17-569)	123(17-571)	121(17-561)	128(18-592)	230(27-1,118)	862(154-3,649)
Outpatient Visits (OPV)	215 (151-280)	207 (145-270)	208 (146-271)	204 (143-266)	216 (151-281)	396 (287-507)	1,408 (921-1,899)
Emergency Room Visits (ERV)	26(8-56)	25(8-54)	25(8-54)	25(7-53)	26(8-56)	52(15-110)	147(43-316)
Respiratory Hospital Admission (RHA)	235(59-529)	227(57-510)	227(57-512)	224(56-503)	236(59-531)	452(113-1,018)	1,405(351-3,162)
Work Day Loss (WDL)	58(29-87)	56(28-84)	56(28-84)	55(28-83)	58(29-87)	89(44-133)	510(255-765)
Acute Respiratory Symptoms (children)	10(8-13)	10(7-13)	10(8-13)	9(7-13)	10(8-13)	17(14-22)	74(55-102)
Acute Respiratory Symptoms (adults)	57(50-65)	55(48-63)	55(48-63)	55(47-62)	58(50-65)	104(91-116)	392(329-454)
Chronic Respiratory Symptoms (children)	34(29-41)	33(28-39)	33(28-39)	32(28-39)	34(30-41)	52(45-63)	299(259-358)
Chronic Respiratory Symptoms (adults)	235 (200-269)	227 (193-260)	227 (194-261)	223 (191-256)	236 (201-271)	361 (308-414)	2,068 (1,764-2,372)
Asthma Attacks (AA)	3(1-15)	3(1-15)	3(1-15)	3(1-15)	3(1-16)	4(1-24)	25(5-136)
Total Ancillary Benefits	**5,722 (2,613-13,997)**	**5,522 (2,522-13,508)**	**5,538 (2,529-13,547)**	**5,443 (2,486-13,315)**	**5,748 (2,625-14,061)**	**11,120 (5,065-27,333)**	**33,404 (15,347-80,764)**
Ancillary Benefit per ton carbon (USD/tC)	**100 (46-245)**	**132 (60-323)**	**97 (44-237)**	**89 (41-219)**	**94 (43-231)**	**185 (84-456)**	**278 (128-673)**

To compare this result with ancillary benefit literature from other countries, ancillary benefit per ton of carbon is also given in the last row of Table 6. The estimations of carbon dioxide reductions are calculated using emissions coefficients[5], combustion efficiency and coal consumption[6] for each electricity generation technology option. Average ancillary benefits per ton of carbon (tC) can then be obtained by averaging total ancillary benefits over total carbon dioxide emissions.

In the literature, the values of ancillary benefits per ton carbon are very divergent, ranging from around USD 2 to more than USD 500 (Davis, Krupnick and Mcglynn 2000; Davis, Krupnick and Thurston 2000). For example, Burtraw and Toman (1997) estimated that the ancillary benefits in the United States is positive but less than 10 USD/tC; Boyd, Krutilla and Viscusi (1995) and Rowe, Lang and Chestnut (1995) estimated 24–40 USD/tC in the U.S., Cifuentes et al. (2000) estimated 62 USD/tC in Chile, and RIVM (research for man and environment) (2000) estimated 53–79 USD/tC in the European Union. These values are all below 100 USD/tC. However, other studies show ancillary benefits could be very high. For example, Ayres and Walter (1991) estimated 165 USD/tC in the U.S., Pearce (1992) estimated 195 USD/tC in the U.K. while Alfsen, Brendemoen and Glomsrod (1992) estimated 102–146 USD/tC in Norway. There is also some literature giving range estimations, such as Barker (1993) (44–201 USD/tC in the U.K.), Dessus and O'Connor (1999) (150–300 USD/tC in Chile), and the biggest estimation by Brendemoen and Vennemo (1994) in Norway – about 840 USD/tC (IPCC 2001b).

This paper found the ancillary benefits in Guiyang to be around the median estimate of the above studies. Due to the potential significance of the ancillary benefits, cost-benefit analyses to determine whether resultant ancillary benefits exceed their mitigation costs are required for policy decision-making.

6.4 Cost-Ancillary Benefit Analysis (CABA)

In the cost-ancillary benefit analysis, both the ancillary benefits and the investment costs of GHG mitigation technology options need to be compared with respect to the baseline pulverized coal-fired power plant. Usually GHG mitigation technology options incur a higher capital cost than baseline technology options, but with improved combustion efficiency and pollution reduction processes, fuel use and pollution emissions are greatly reduced, so that the fuel costs and environmental costs are lower. Table 2 shows the detailed technical parameters for the selected GHG mitigation technologies.

Consider a 300MW IGCC plant as an example for a crude CABA – the difference in initial capital investment costs between an IGCC plant and an equal-capacity baseline subcritical pulverized plant is 470 USD/KW at the project start year. Since an IGCC plant is more efficient than a baseline pulverized plant, fuel use will be lower while generating the same amount of electricity each year. With the use of an advanced boiler system, expensive equipment, and high-skilled labor, fixed and variable costs each year increase from 0.871

[5] CO_2 emissions coefficients (in kgC/kgce): 0.725 for coal, 0.583 for oil, and 0.409 for natural gas. Since most of the enterprises investigated are using coal, 0.725 is used here for calculation. Source: ADB, World Bank, and UNEP, Summary of International Studies on the Outlook for China's Energy Consumption and CO_2 Emissions, Washington DC, July 1999.

[6] Source: carbon dioxide reductions are estimated from the Guiyang 1998 industrial survey by timing the emission coefficients of coal with reductions in coal consumption after adopting GHG mitigation projects.

cents/kwh to 0.981 cents/kwh. However, fuel costs are reduced from 0.968 cents/kwh to 0.784 cents/kwh. Now assume the operation hours for both technologies are 6000 hours per year. Compared with the baseline pulverized technology, IGCC technology can save 4.4 USD/KW (the calculation is $(0.981 + 0.784 - 0.871 - 0.968)\times 0.01\times 6000 = 4.4$ USD/KW). We can now calculate the average ancillary benefits to be about 19.1 USD/KW each year (dividing total ancillary benefits of USD 5,722 million by a total capacity of 300 MW). The annual net benefit is 23.5 USD/KW (19.1 + 4.4 = 23.5 USD/KW), which was used in a cost-benefit analysis framework by comparing it with the initial 470 USD/KW capital cost. The discount rate is assumed to be from 0% to 15% in the sensitivity analysis done. Similar calculations for the remaining GHG mitigation technology options in the electricity sector were carried out and compared with the baseline pulverized power plant. The net present values (NPVs) for all these GHG mitigations are shown in Figure 10.

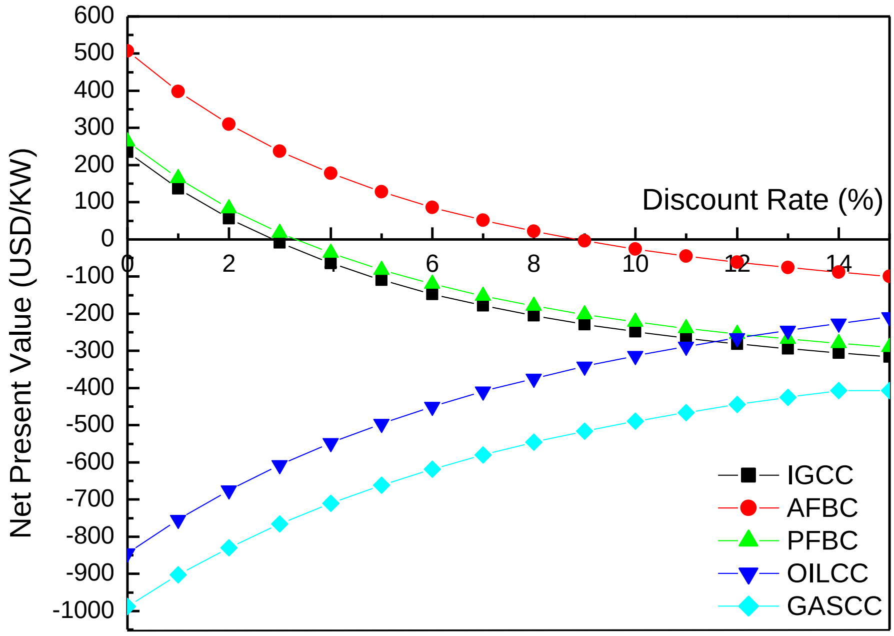

Figure 10. Sensitivity analysis of net present values of ancillary benefits of GHG mitigation options for electricity generation

The sensitivity analysis of the CABA results show that AFBC is the most favorable GHG mitigation option. If the discount rate is less than about 12%, the next best option will be PFBC, followed by IGCC. For OILCC and GASCC, their initial capital investment is lower than the other options, but their annual fuel costs are very high, resulting in negative net present values especially when the discount rate is lower.

This paper also analyzed industrial boiler mitigation options. There is very little cost data available on this sector, so in this study, crude estimates of the mitigation costs were taken from ADB (1998), listed in Table 7. For the studied area of urban Guiyang, the estimated total capacity of boiler systems is about 2500 steam-t (industrial boiler capacity unit) (China Natural Resource Database 2003) and the estimated total coal consumption for industrial use is 3.22 million tonnes (GYAEMIS database 2001).

For the existing industrial boilers, the annual costs of fuel pretreatment and existing boiler system renovation are USD 64.5 million. The total cost of replacing all old boiler systems with advanced, efficient boiler systems is USD 271.7 million. Based on the estimated ancillary benefit results calculated in section 6.4, this study conducted CABAs for industrial boiler mitigation options as well. The sensitivity analysis results are shown in Figure 11. When the discount rate is higher, the more conservative GHG mitigation option of coal pretreatment and boiler renovation is preferred over applying new efficient boiler systems, and vice versa.

Table 7. Abatement costs for industrial boiler mitigation options

Description of GHG emissions abatement options	**Potential time frame** (years)	**Estimated capital cost** (USD/typical size) (in 1998 prices)
Fuel pretreatment	1994-2010	USD 4.1 / t-coal
Renovation of boiler combustion system	1994-2010	USD 12,740 / steam-t
Efficient boiler application	1994-2010	USD 53,670 / steam-t

Source: Adapted from ADB (1998), p61.

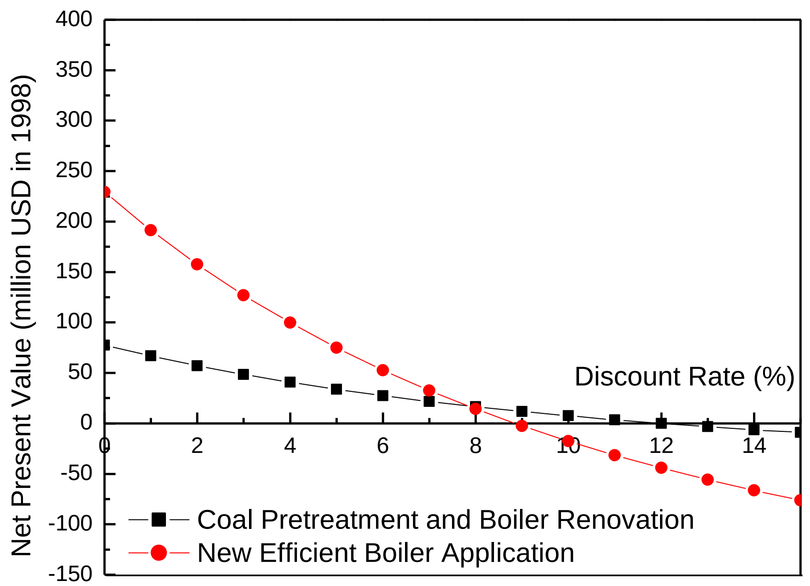

Figure 11. Sensitivity analysis of net present values of ancillary benefits of GHG mitigation options for industrial boilers

From the above CABAs, it is clear that the ancillary benefits are an important part of the total benefit, which can offset a large part of GHG mitigation costs. In addition, for most GHG mitigation options in both the electricity and industrial sectors, except OILCC and GASCC whose fuel costs are too high to bear for the time being, there is always some positive net present value over some positive discount range. Therefore, ancillary benefits are very important in policy decision-making, either to rank favorable GHG mitigation options or to determine whether the social benefits exceed the GHG mitigation costs.

This CABA study used "best guess" values of ancillary benefits to compare the social benefits and mitigation costs. It is also possible that these "no regrets" options, which bring positive net social benefits, might not be favorable when using lower estimates in determining dose-response and unit values of mortality and morbidity endpoints, or could result in much higher net present values if using higher bound estimates. Therefore, uncertainty over ancillary benefit estimation critically affects cost- ancillary benefit analyses. For this reason, this paper also uses the lower bound estimates as a conservative measure in the sensitivity analyses. As it turns out, when the discount rate is less than 5%, the associated ancillary benefits of AFBC still exceed the GHG abatement costs. With the industrial boilers, the coal pretreatment and existing boiler renovation options can only obtain a positive net present value when the discount rate is less than 2%. Using the lower bound estimates, the application of new, efficient boiler systems would no longer be a “no regrets” option.

Another issue regarding the practical estimation of ancillary benefits in local policy decision-making is its costly and complex calculation, as well as the time-consuming collection of meteorological and pollutant industrial data. Air dispersion modeling also requires complicated modeling work and calculation. In addition, VSL and WTP indigenous studies for local cities in China are very few. Therefore, it may not be appropriate for all urban cities in China to conduct ancillary benefits analyses. However, this paper gives a sample reference for decision-making in other cities as well.

There are several ways to simplify the calculation steps for quick decision-making. Since the whole ancillary benefit estimation flow sheet is quite similar to local EIA (Environmental Impact Assessment) processes, some literature suggests that governments should consider incorporating ancillary benefit analyses into existing EIA frameworks to aid decision-making, or use them qualitatively as a standard checklist (Markandya 1998; Davis, Krupnick and Mcglynn 2000). But such a checklist would need to be based on many detailed case studies like the Guiyang case in this paper. Therefore, if more extended CABA studies could be conducted, a database of such case studies would eventually reduce the technical costs of estimation, making policy decision-making faster and more efficient.

7.0 CONCLUSIONS AND POLICY RECOMMENDATIONS

This study uses a bottom-up approach to valuate various GHG mitigation technology options in Guiyang by incorporating the value of ancillary benefits into a cost-benefit analysis. The results show that ancillary benefits are very substantial and should be incorporated into the policy decision-making framework. In addition, by comparing different potential GHG mitigation technology options, this paper found that AFBC is the most favorable option in the electricity sector for local Guiyang. If the discount rate is lower than 8%, using new efficient boiler systems would be more favorable than using coal pretreatment and renovating existing boilers. But if the discount rate is higher than 8%, the latter is more attractive. The sensitivity analysis shows that the net present values of the net benefits are very sensitive to the discount rate, dose-response value and unit value for mortality and morbidity endpoint selection. A CABA study at the lower bound is, therefore, the most appropriate tool for conservative decision-making.

Also related to the cost-effectiveness of GHG mitigation options is the issue of implementing local pollution control measures rather than obtaining secondary benefits from GHG mitigation. As O’Connor et al. (2003) and Aunan et al. (2000) show in their Guangdong and Shanxi case studies, the overlap between the most cost-effective GHG mitigation option and the most cost-effective local pollution control option is quite large. Therefore, the two objectives are not as discrepant as they might seem, in terms of actual implementation. In addition, the ancillary benefits study provides an alternative incentive for governments to improve local environmental quality, which could attract early CDM (Clean Development Mechanism) funding.

Although this analysis has provided enough information for local governments to act upon immediately, there are still many issues to be solved prior to actual implementation. In the following section, the existing economic and institutional barriers facing government policy-making will be discussed followed by an exploration of the potential opportunities which Guiyang or China could take advantage of, and finally policy recommendations for actual implementation of cost-effective GHG mitigation technology options are given.

7.1 Economic and Institutional Barriers

This CABA study found that the ancillary benefits of adopting clean technology exceed the private costs. However, private firms care more about the private costs of adopting clean technologies, especially when they face expensive capital investments at the start of a project. Therefore, without compensation from the government, the ancillary benefits cannot be easily incorporated into private decision-making. It requires some sort of governmental subsidy or tax credit policy to induce private firms to implement the GHG mitigation options recommended in this study. In addition to this key barrier, other economic and institutional barriers are as listed below:

- Insufficient Information

China has gained substantial benefits from the economic reforms of the late 1970s. For example, the market is much more efficient and open, and policy-making at state and local levels is beginning to include cost-benefit analyses. But in the climate change field, China still does not have enough information, especially as to the future benefits of immediate carbon emissions reduction. Therefore, without a clear view of the costs and benefits, even the most rational economist could make a wrong decision, or he may just take a “wait-and-see” stance. The bias that is due to the imperfect information actually exists in every country including most Annex I countries. However, this problem is more prominent in China. Many current climate change and energy policies are being established without considering any ancillary benefits in the policy-making framework simply because of a shortage of information.

- Weakness in Financial Capacity and Poor Credit Facilities

Even if state or local governments knew which projects would be “no regrets” ones, and the private sector had the incentive to invest, initial capital outlay and operating costs are still too high for investors or local governments to bear. In addition, small-medium enterprises and small energy projects in China find it difficult to obtain bank loans or credit. Government and bank officials are typically hesitant to provide credit for investments with long-term or indirect payback, especially when investing in environmental-friendly or energy-efficient technology projects. Although current foreign investment and bilateral and multilateral Official Development Assistance (ODA) provide partial support, these funds are not nearly enough to implement GHG mitigation activities.

- Lack of Entrepreneurs and Adequately Skilled Workers

In general, most GHG mitigation projects such as clean coal projects, clean production and renewable energy projects, are implemented at local levels. Therefore the decision-making at the firm level is very critical. Chinese business managers, however, usually have a restricted and myopic view of advanced energy-efficient technologies. Part of the reason for this is their very limited access to proper information on GHG technologies and foreign investment opportunities. Meanwhile, the technical training of equipment operators and the environmental awareness of government officials are also limited in Guiyang, mostly because of its less developed economic, social and education status.

- Imperfect Market System and the Problem of State Owned Enterprises (SOEs)

To stimulate the extensive use of efficient energy technologies, a key factor is building a mature market with a good legal and institutional framework. Although market-based economic policies have been initiated in China, the market system has not matured yet. Furthermore, although energy is now priced by the market, the impacts of governmental intervention in State Development Planning Commission (SDPC) planning, such as increasing incentives to use raw coal as the main source of energy, may distort the true market price of different energy sources. Similarly, SOEs[7] are used to receiving subsidies and incentives provided under the former government regime, and may not be as competitive as private and foreign enterprises. Domestic private and foreign enterprises, although financially strong, find it difficult to enter the energy industry which is still dominated by government monopolies. As a result, the current problem is how to make the whole market system more transparent and competitive.

- Lack of Effective Policy Enforcement

Compared with many developed countries such as the U.S.A., environmental policy enforcement is still very weak in China, both in fee collection, taxation, as well as in direct regulation. Environmental laws have been established, but their provisions are too general for implementation. Pollution charge collection is not strictly enforced in many areas of China, especially the rural areas. The lack of effective policy enforcement reduces the incentive to employ clean and environmentally-friendly technologies.

7.2 Current Opportunities

Although many barriers exist, there are still many opportunities for China to take advantage of. The most significant opportunity may well be China's entry into the World Trade Organization (WTO). It is estimated that tariffs on industrial products will decline significantly from 17% to 9% (Logan 2000). Therefore, financial investment and technology transfer from other countries will be able to flow much more easily into China. In addition, bank reforms will further improve the speed of Foreign Direct Investment (FDI) and technology transfer.

The second opportunity is that China's energy-use efficiency is still very low. In 1997, total energy efficiency was only 31.2%, much lower than the U.S. and Europe. Therefore China has plenty of scope for future energy saving.

Thirdly, although skilled human resources are limited in many areas all around China, some human capital has been accumulated from extensive training during technology demonstrations under FDI and ODA loans from the United Nations Development Programme

[7] SOEs: In the energy sector, SOEs are still the main enterprises in the electricity market. The competition in electricity is mostly from local provincial or regional entities.

(UNDP), World Bank, and other such bodies. Although these projects were limited in number and scale, technology and personnel training has helped China along its learning curve. The challenge is how to use the trained human capital (found mostly in big cities) in implementing energy-efficient technologies and accelerating technology transfer.

If China were to take an international perspective and adopt a positive climate change policy, it will more easily attract early funds and competitive CDM projects (Caspary and O'Connor 2002). The benefits would definitely outweigh what China gained on the negotiation table for ozone funds. Therefore, the longer China waits to implement "no regrets" projects, the more China loses.

7.3 Policy Recommendations

From the above policy analysis, some policy recommendations are proposed to facilitate the adoption and transfer of GHG mitigation technologies in China, and at the same time, achieve synergy with respect to local environmental needs and global environmental concerns.

- Establish Beneficial Climate Change Policies and Strategies

Although China took part in many international activities on climate change (such as the Inter-governmental Panel on Climate Change Workshop), and enacted some related public policies (most of which were actually already included in other environmental policies and laws), no real climate change policies or strategies were actually implemented. As mentioned earlier, only an environmentally-supportive climate change policy will enable China to strongly compete with other developing countries for future CDM projects.

- "Learner's Advantage" Strategy

As a developing country, China is economically and technologically far behind developed countries. Followers can, however, benefit by taking advantage of the "Learner's Advantage" strategy. For example, China does not need to spend huge human and physical capital on R&D to explore what the most technically efficient GHG mitigation technologies are. Many developed countries have studied these problems in depth over a long period of time and their research and demonstrative project reports are easily available as reference. As analyzed earlier, China has immense scope to grow and benefit from technology transfer. Based on this logic, if China launches CDM projects early, the gain from the advanced CDM technologies would bring great benefits, either from earlier technology transfer or human capital growth. Thus China has much to lose by taking a "wait-and-see" stance.

- Take Advantage of WTO Entry and CDM Opportunities

With China's WTO membership, not only will the technology transfer become much easier, but it will also stimulate the establishment of a series of market-oriented reforms, such as improved capital market financing, better investment terms for high-risk industries, and improved laws and enforcement. These institutional changes will further develop a competitive market system, foster an entrepreneurial state, and set up new market ideologies and infrastructures; benefits far exceeding the benefits of tools and equipment. In addition, the improved government structure and powerful legal system will further improve efficiency and attract foreign investment in the long run.

Moreover, with the possibility of the Kyoto Protocol coming into force in the near future, taking advantage of Clean Development Mechanisms (CDMs) to attract Foreign Direct Investment from Annex I countries could help facilitate GHG-friendly investments and technology transfer. Meanwhile, the Annex I countries get certified emissions reduction (CERs) credits at less cost. Therefore, it is a "win-win" solution for both countries. Current studies show that small CDM projects in China have the highest potential for the time being (OECD 2001).

- Selecting "No Regrets" Projects and Related Policies Based on Local Situations

Although many ancillary benefit studies are conducted at state level, ancillary benefits are actually gathered locally. For instance, IGCC may be profitable in area A, but may not be profitable in area B, due to many factors such as different geographical characteristics, pollutant dispersion processes or discrepencies across different groups of people in willingness to pay for environmental quality. Therefore, when the local government implements energy policies or selects CDM projects, the selection should be based on specific local needs. On the other hand, state governments or the SDPC should craft a broad energy policy framework within which local governments can make decisions of their own in setting priorities for different "no regrets" mitigation options.

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